Earth Surface Processes and Landforms
Earth Surf. Process. Landforms **24,** 65–70 (1999)

TECHNICAL COMMUNICATION

HORIZONTAL WATER TRAP FOR MEASUREMENT OF AEOLIAN SAND TRANSPORT

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Received 30 August 1997; Revised 14 February 1998; Accepted 18 June 1998

ABSTRACT

A new type of horizontal trap was developed for measuring the aeolian sand transport rate on a flat surface. The trap consists of an adjustable frame that is embedded level with the sand surface, into which a plastic liner is installed and filled with water to capture the blown sand. The water trap has high efficiency and does not disturb the wind field or induce upwind scour. Deployment on Padre Island, Texas, indicated that this portable and adjustable trap catches and retains all the sand blown into it, even under relatively strong wind. Copyright © 1999 John Wiley & Sons, Ltd.

KEY WORDS aeolian sand transport; wind-blown sand; aeolian sand trap; sediment transport; Padre Island, Texas

INTRODUCTION

Traps for measuring the aeolian sand transport rate are classified as either the vertical or the horizontal type (Horikawa and Shen, 1960). A vertical trap stands erect on the sand surface and catches sand passing into its compartments. A horizontal trap is simply an opening or hole in the sand surface into which blown sand falls. Most field measurements of the aeolian transport rate have been made with vertical traps (e.g. Horikawa and Shen, 1960; Leatherman, 1978; Fryberger *et al*., 1984; Goldsmith *et al*., 1990; Bauer *et al*., 1996). Relatively few field measurements have been made with horizontal traps (Kubota *et al*., 1983; Horikawa *et al*., 1984; Hotta, 1984; Greeley *et al*., 1996). Simultaneous measurements made with both vertical and horizontal traps at the same location have yielded unsatisfactory comparisons (Horikawa *et al*., 1984; Greeley *et al*., 1996), and it has been concluded that horizontal traps are more efficient (Hotta, 1988). Field horizontal traps tend to be cumbersome, involving the digging of deep trenches and difficult extraction and weighing of large amounts of trapped sand.

In the present study, a portable and adjustable horizontal trap was designed and deployed at Padre Island, Texas. Water serves as the trapping mechanism, instead of screens for vertical traps and deep ditches for horizontal traps.

OVERVIEW OF AEOLIAN SAND TRAPS

Several factors enter the design of sand traps for measurement of aeolian sand transport. High and constant trapping efficiency is the most prominent. Other factors include cost, ease of mobilization and demobilization, and ease of extracting and weighing the sand collected.

Vertical traps

There are many styles of vertical trap, but all operate by standing erect and presenting an obstruction to the wind and blown sand. Various trapping-element alternatives, e.g. sieve cloth, cylindrical and V-

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CCC 0197-9337/99/010065–06 $17.50

shaped traps, have been implemented to reduce the obstruction (e.g. Horikawa and Shen, 1960; Leatherman, 1978; Kubota *et al.*, 1983; Illenberger and Rust, 1986). Whatever the mechanism for capturing the sand, some disturbance to the wind field, hence distortion or weakening of the wind at the trap, must occur for a vertical trap to function. The efficiency of vertical traps can be significantly lower than unity. Knott and Warren (1981) found that a modified Bagnold (1938) vertical trap had efficiency of only 20 to 40 percent. Horikawa *et al.* (1984) also found that vertical traps had low and unstable trapping efficiency. Efficiencies of 10 to 15 per cent were suggested by recent studies on vertical traps (Arens and van der Lee, 1995; Bennet and Olyphant, 1998). All the above studies indicated that the efficiency of the vertical traps varied with the wind speed and surface condition. Scouring at the base of vertical traps is commonly observed in the field (e.g. Knott and Warren, 1981; Fryberger *et al.*, 1984; Hotta, 1988; Horikawa, 1990), indicating disturbance of the wind at the base of the trap. To reduce scour, the sand surface in the vicinity of vertical traps has been wetted (Kubota *et al.*, 1983) or covered by a plate (Fryberger *et al.*, 1984), creating an unnatural condition.

Vertical traps typically have opening lengths of several to a few tens of centimetres, similar to the wavelength of surface sand ripples. The presence and migration of sand ripples can significantly alter the trapped sand amount for such small openings (Hotta, 1984; Horikawa *et al.*, 1984; Pye and Tsoar, 1990). Therefore, small vertical traps are not suitable for measuring the average sand transport rate under most field conditions.

Vertical traps have advantages of portability, simple installation and convenient sediment retrieval. They can be advantageously designed to self-align to wind direction during the measurement (e.g. Bagnold, 1938; Fryberger *et al.*, 1984) and can also measure the vertical profile of the sediment flux (e.g. Chepil, 1945; Horikawa and Shen, 1960).

Horizontal traps

Field applications of horizontal traps have been limited because of operational difficulties and lack of portability. A large trench trap, 6m wide (trap width runs parallel to the wind direction), 2m deep and over 50m long (trap length runs perpendicular to direction of wind), was tested by Horikawa *et al.* (1984), Kubota *et al.* (1983) and Hotta (1984). The sand volume trapped in the trench was determined by recording the elevation of the sand surface at scaled rods, as well as filming sand infilling at the windward side of the trench by video camera. Greeley *et al.* (1996) operated a horizontal trap 3m wide, about 0·5m deep and 10m long that was divided into many sand-collection bins for efficient sand retrieval and study of the saltation distance. The sheltering of the sand-collection bins also effectively reduced the depth requirement of the trap.

Disadvantages of these (dry) horizontal traps are that they must be dug deep enough so that the captured sediment cannot be remobilized and blown out of the trap, as well as wide enough so that sand grains cannot fly over the trench. Other uncertainties may be introduced through difficulties in quantifying the large amount, typically hundreds to even thousands of kilograms, of sand. The measurement duration typically spans several hours to days, making difficult the correlation between transport rate and wind forcing. Because of the large scale of previous horizontal field traps, error is introduced in not being able to start and end the measurement instantaneously and in quantifying the trapped amount in the presence of wind (Horikawa *et al.*, 1984). Also, such large horizontal traps are not capable of self-adjusting to variations in wind direction.

A small self-recording horizontal trap was described by Jackson (1996). Instead of measuring the total transported sand passing a certain length as in previous horizontal traps, the Jackson (1996) trap measures the mass trapped in a certain horizontal area (a 24cm diameter circle in this case). The Jackson (1996) trap eliminates the necessity of large trap width based on the assumption that the blown sand rate is uniform in the direction of motion. However, the relationship between the mass measured by the Jackson trap and the total transport rate measured by previous and present horizontal traps is not clear.

The major advantage of horizontal traps is that they do not disturb the wind field and its sand-

transporting capacity. It is reasonable to conclude that the trapping efficiency is close to unity if the trapped sand is not remobilized and blown out of or over the trap. The dimensions of field horizontal traps have typically been much larger than those of surface sand ripples. The influences of the existence and migration of ripples to sand trapping are averaged out or minimized by a suitable sampling time interval.

Comparison of traps

Because of the disturbance of the wind field and the unknown influence of small-scale surficial sedimentary structures, the efficiency of vertical traps is relatively low, difficult to determine, and may vary with wind speed and sand-surface conditions. Although highly portable and easy to install, the small scale and intrusive nature of vertical traps raise significant questions about the determined transport rates. Horizontal traps are difficult to operate, time-consuming due to the large amount of sediment collected, and lack mobility, but they have efficiencies approaching unity and are not significantly influenced by small surface sedimentary structures. These advantages make the horizontal trap more suited to measurement of an average total transport rate (averaging intervals of minutes to hours) than vertical traps. Because of the potential high efficiency of horizontal traps, improvement in their design was investigated in the present study. Owing to their high trapping efficiency, horizontal traps can be used to determine the trapping efficiency of vertical traps.

NEW HORIZONTAL WATER TRAP

Water is a perfect trap for aeolian sand. A horizontal trap filled with water can reduce the depth requirement of a horizontal trap, because the captured sand cannot be remobilized and transported. In comparison with dry horizontal traps, the size of water horizontal traps can be significantly reduced by eliminating the depth requirement, with water serving as the trapping mechanism rather than wind sheltering by depth. It has been established (e.g. Bagnold, 1941; Horikawa, 1990; Pye and Tsoar, 1990) that most aeolian sand larger than 0·1 mm diameter is transported in the modes of saltation and surface creep. The width of horizontal traps should be sufficient to capture not only saltation and surface creep sand, but also the sand moving in short-term suspension and/or modified saltation (Nalpanis, 1985) for the given wind conditions. The length of a trap should be sufficient to average out the variations caused by migratory surface sand ripples.

With the above considerations of the width and length of horizontal traps, we designed a portable and adjustable horizontal water trap (Figure 1) for measurement of aeolian transport. The perimeter of the trap, assembled in the field, is formed by plywood (or aluminium) sheeting. The dimensions of the trap are adjusted by forming frames with members of different lengths. The trap frame can be installed easily by pounding the sheeting (secured by an angle iron) into the sand. The top 10 cm of sand within the trap frame is removed. A plastic liner (e.g. 1 mm thick plastic cover used widely in horticulture) is placed inside the trap to hold water. Weights, such as iron bars that can be lined inside the trap to hold down the plastic liner, and staples (in this case, plywood sheeting is more desirable) and clamps are helpful in rapidly installing the liner in windy conditions. We recommend installation of at least two layers of plastic liner, so that the top liner, serving as a cover, can be rapidly removed at the beginning of the experiment to allow an instantaneous start of the measurement and minimize the amount of sand that may be trapped during liner installation. The water is drained (and can be recycled for subsequent trap deployments) at the end of the measurement interval. Calgon can be used to reduce the water surface-tension if fine particles float on the water surface. The water drain may be covered with sieve cloth to minimize potential loss of sand.

Two water traps, one 2 m long and 1·5 m wide (Figure 2), and the other 1·5 m long and 2 m wide, were deployed on Padre Island, Texas, with wind speed ranging from 4 to 9 m s^{-1} (as measured 1 m above the sand surface). The mean sediment grain size at the field location is approximately 0·2 mm. Adequacy of

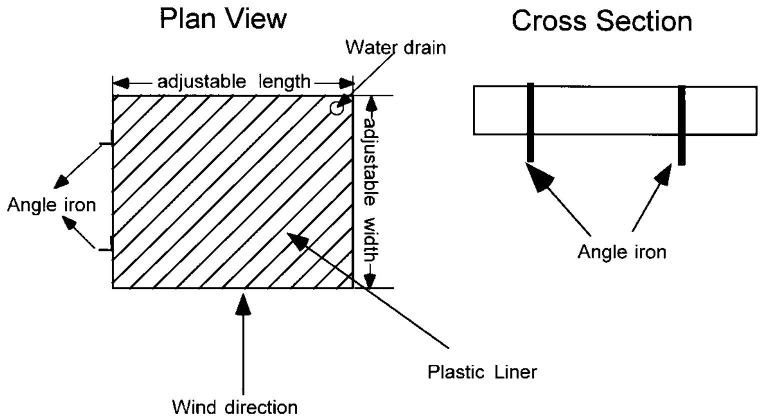

Figure 1. Schematic design of the water trap

Figure 2. Field deployment of the water trap on Padre Island, Texas. Sand is blowing from south to north (left to right), as can be seen from scour around the shovel in the right foreground and the full extension of sieve-cloth bags of a vertical trap in the left background

the width of the trap can be determined in the field by extending the plastic liner (wetted) to a certain distance behind the trap (Figure 2) and monitoring the amount of sand trapped on the plastic surface. We found that a 1·5m wide water trap was sufficient for trapping fine sand transported by wind with speed less than $9\,\mathrm{m\,s^{-1}}$. It is worth conducting some tests to determine an optimal length and width ratio. The wider the trap, the smaller the possibility of sand flying over it, whereas the longer the trap, the less sensitive to wind-direction variation.

Installation of traps of the stated dimensions by two people took about 40 min. Clamps and weights (sand bags or metal rods) were helpful in holding down the plastic liner in wind. The trapped sediment was retrieved by draining the water and removing the plastic liner with the sediment wrapped inside. The sediment retrieval takes less than 10 min for two people. If wind direction remains constant, a subsequent measurement only requires placement of a clean liner in the existing frame, which takes less than 15 min. The sand measurement can be terminated instantaneously by covering the trap with a plastic liner.

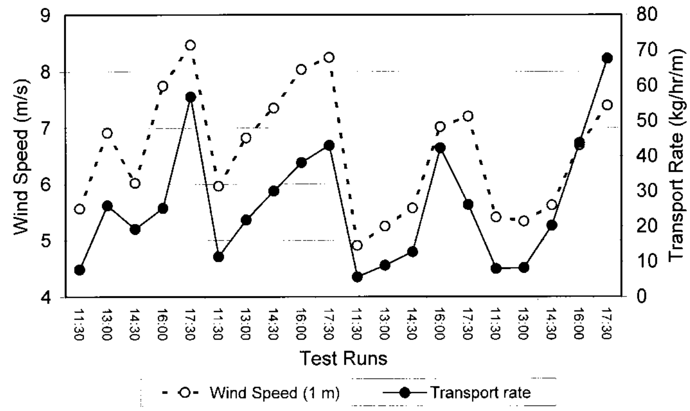

Figure 3. Examples of field test of the water trap. The amount of trapped sand increases as the wind speed increases towards the early evening. The wind speed was measured at five elevations; the 1 m wind speed is used in this illustration

A typical field measurement included the following steps: (1) selecting a fairly flat area and determining the proper dimensions of the trap; (2) installing the trap frame; (3) removing the top 10cm of sand; (4) laying out three layers (in three-fold) of plastic liner; (5) tearing off the top layer of the liner and starting the timer; (6) filling the trap with water; (7) covering the trap and stopping the timer; (8) draining the water; and (9) removing the liner with sediment wrapped inside.

A series of trials on measurement duration, ranging from 20 to 85 min, was conducted with the horizontal water traps. Measurement duration of 30 min was found sufficient for trapping tens to hundreds of kilograms of sand (dry weight) for a 2m long trap under the wind speeds encountered. The performance of the horizontal water trap was determined to be stable under a variety of wind speeds. No scour was observed at the windward edge of the water trap (observe lip on left side of trap in Figure 2). The scour observed at the leeward of the trap did not influence the measurement. An increasing amount of sand was trapped as wind speed increased from noon towards early evening (Figure 3). Correlation of aeolian sand transport rate and wind forcing associated with these measurements will be presented in another publication, under preparation by the authors.

A disadvantage of the present design lies in transporting, drying and weighing large amounts of samples. Reduction of trap dimensions consistent with wind speed and ripple migration can minimize collected volume. Accessories including weights, clamps, etc., are always helpful in liner installation. Extra layers of liner, which can serve as covers, are helpful in executing an instantaneous start of measurement.

SUMMARY AND FUTURE IMPROVEMENT

A portable and adjustable horizontal water-filled sand trap was designed and successfully tested for aeolian sand-transport studies. Moving sand is trapped efficiently by shallow water as an alternative to sheltering by a deep dry trap, and the desirable characteristic of not inducing scour is maintained. The horizontal dimensions of the water trap can be adjusted conveniently according to the wind speed and surface conditions. Installation and sediment retrieval took less than 1hr for a trap 1·5m wide and 2m long in relatively strong wind. The trap may be readily modified by dividing it into small compartments to determine saltation distance. The water trap also has the advantages of low cost and easy construction. Rapid turn-around time between deployments permits changes to be made in trap orientation in response to changes in wind direction. The main disadvantage of the present design involves the labour-intensive post-processing of large amounts of wet sand.

ACKNOWLEDGEMENTS

We would like to thank Dan Heilman and Daryl Slocum, formerly of the Conrad Blucher Institute (CBI), Texas A&M University–Corpus Christi, for assistance in the field and with instrumentation, respectively. We appreciate review of an early version of this paper provided by Dr S. A. Hsu, Louisiana State University (LSU). The fieldwork and trap development were sponsored by Nueces County, Texas, as part of the Packery Channel Feasibility Study conducted by CBI. P.W. appreciates the support of Dr Gregory Stone, Coastal Studies Institute, LSU. N.C.K. acknowledges permission granted by Headquarters, US Army Corps of Engineers, to publish this paper prepared under support of the Coastal Inlets Research Program, Inlet Channels and Adjacent Shorelines Work Unit. We are grateful to Professor Ken Pye and an anonymous reviewer for a critical and helpful review of this paper.

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